SEISMICITY

The Savannah River Plant is located in an area where moderate damage might occur from earthquakes, based on earthquake risk predictions by the U. S. Coast and Geodetic Survey (Figure II-48).[21] The spatial distribution of South Carolina earthquakes, with respect to southern Appalachian seismicity, is shown in Figure II-49.[22] On the basis of three centuries of recorded history of earthquakes, an earthquake above an intensity of VII on the Modified Mercalli (MM) scale would not be expected at the Savannah River Plant. Average acceleration from Reference 23 for intensity VII corresponds to 0.13 g. During the past 100 years, the area within a 100-mile radius of the Savannah River Plant has experienced one shock of intensity X, one shock of intensity VIII, two shocks of intensity VII, and 12 shocks of intensity V MM. Seismic monitors, which were installed in SRP reactor buildings between 1952 and 1955, are set to alarm at 0.002 g (intensity II) and have never indicated an earthquake shock of this intensity since their installation. The design basis earthquake (DBE) for SRP incorporates an acceleration of 0.2 g.

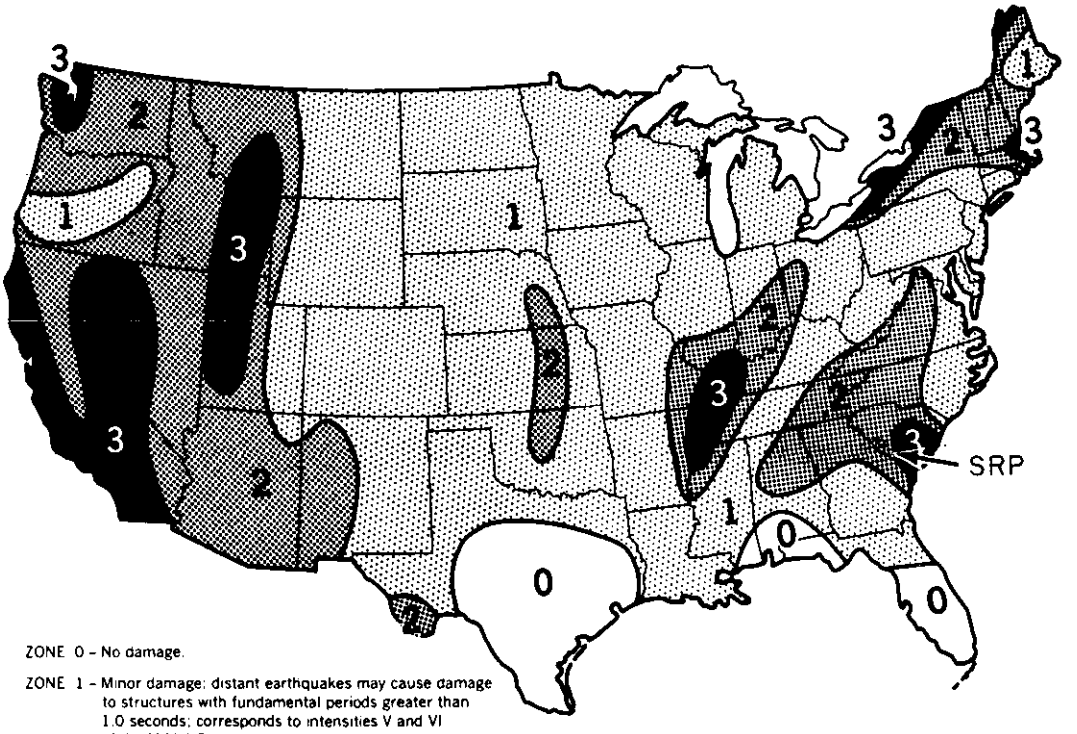

FIGURE II-48. Seismic Risk Map for United States

Before the 1886 Charleston earthquake, the seismic activity in the southeastern part of the United States was low. No severe earthquake shocks had their origin in South Carolina or Georgia from the time of settlement by colonists in about 1670 until the Charleston earthquake in 1886.[22] The only shocks of significance felt in the area during this 200-yr period were those connected with the New Madrid, Missouri, earthquake of 1811-1812. These shocks slightly damaged a few brick buildings in Columbia and elsewhere in the state of South Carolina.

The shock of intensity X MM was the Charleston earthquake of August 31, 1886. This earthquake was felt 800 to 1000 miles away. An area of about 2,000,000 square miles was affected (Figure II-50). In contrast, the 1906 San Francisco earthquake with an intensity of XI MM affected an area of only 373,000 square miles. With only minor exceptions, an earthquake of a given intensity in the eastern United States will be felt at much greater distances than a shock of the same intensity in the western United States. This effect is probably due to the more efficient propagation of certain seismic waves in the more uniform crustal structure of the eastern United States.

The Charleston earthquake caused only minor superficial changes to the ground surface. The epicentral region was broken by many fissures through which water issued, but the fissures seldom attained a width of more than one inch. In contrast, the San Francisco earthquake opened fissures up to 5 ft wide at a distance of 15 miles from the fault, and the fault was exposed at the surface. The Charleston earthquake was probably caused by a fault movement in basement rock beneath a half-mile thickness of unconsolidated sediments. There is evidence that the intensity at and near the Fall Line was slightly greater than that nearer to the epicenter of the 1886 Charleston earthquake. This presumably is due to the fact that the sands and clays of the coastal plain sediments provide greater attenuation to seismic waves than do the underlying basement rock. The effect may also be due to resonance of the soil column near the Fall Line.

Damage was greater at Augusta, Georgia, and Columbia, South Carolina, on the Fall Line, than at intermediate locations, as can be seen from Figure II-50.[24] Reports on the effects of the Charleston 1886 earthquake from towns in the vicinity of SRP were used to estimate earthquake intensities (Figure II-51).

Since the 1886 earthquake, Charleston has been the locus of continued seismic activity indicating that the earthquakes are associated with a tectonic structure even though it is obscured by the overlying Coastal Plain sediments. This tectonic structure is responsible for 98%* of all of the historic earthquake activity

* Calculated from listing of earthquakes found in Reference 25.

in the Coastal Plain province of South Carolina and 89% of the earthquake activity in South Carolina.[26] In evaluating the potential for ground motion at SRP, earthquakes of the intensity of the 1886 Charleston earthquake are not assumed to occur elsewhere in the tectonic province.[26]

Earthquakes associated with the Piedmont Province do not seem to be associated with tectonic structures and could thus be assumed to occur anywhere within the province. The maximum earthquake occurred in Union County on January 1, 1913. It occurred about 95 miles from SRP, and its intensity at SRP was about III MM. Since these earthquakes are not associated with a known tectonic structure, they can reasonably be assumed to occur anywhere in their tectonic province, which could be as close as 20 miles from waste management facilities at SRP. If an intensity VI-VII MM earthquake were to occur at this distance, the intensity at SRP would be V-VI MM. At the VI MM level the acceleration would be approximately 0.07 g. Using a similar logic, the maximum earthquake in the Blue Ridge Province and Valley and Ridge Province would result in an intensity of I-II MM and the acceleration would be <0.02 g.[26]

With the installation of many very sensitive seismographs on the South Carolina Coastal Plain and nearby Piedmont Plateau, a greater number of small earthquakes are being recorded. These additions to the statistical record of earthquakes in this area have not changed the conclusions drawn from the 300-yr and human observation of more easily detectable earthquakes. However, as these refined observations contribute to the understanding of crustal structure and tectonics in this area, they may permit a determination of the potential for strong earthquakes in this region.

Intensified geologic studies have revealed a fault northwest of Augusta, Georgia, along the Fall Line, in which crystalline metamorphic rocks are faulted up against sediments of the Tuscaloosa formation and in one area, against sediments that were reworked from the Tuscaloosa formation. Radiocarbon dating of slightly organic clays within the fault zone indicate that the age of the fault is less than 2450 years old. Dating of other organic clays in the vicinity but not actually cut by the fault, give ages as recent as 400 years. Thus, indications are that this fault should be considered in evaluating possible vibratory motion at SRP. The USGS has studied this fault, but the rate and character of its movement has not yet been resolved, nor has its significance to the tectonic framework of the eastern United States been determined. A rough estimate of the intensity of a postulated earthquake was made using available information on the fault,[27] and assuming sudden movement along the entire length of the fault.[28] This results in an earthquake with an

maximum intensity of IX MM. Estimates of the intensity at SRP (30 miles from the fault) would be VI-VII.3 MM.[29,30] The lower value was determined using data from Reference 29 that is based on extensive California attenuation data, and the higher value assumes attenuation to be similar to the Central United States.[30] This would be equivalent to vibratory ground motion of 0.07 to 0.16 g.[23] As more is learned about this fault, its significance will be reassessed.

BIOTA

Plants, birds, and animals must be considered in any waste management policy because of their ability to mobilize radioactivity present in the environment and thereby permit it to be dispersed and to enter the food chain of man. The Savannah River Plant site provides a wide variety of protected habitats; hence, the species diversity and populations are both large. In general, the plantsite is a natural preserve for biota typical of the southeastern Coastal Plain. The production and support facilities occupy only a small portion of the plantsite, and wildlife is little affected by them. Radioactive releases are limited to low levels in limited areas and have had no significant effect on the wildlife.

Habitat Conditions

Before construction of SRP in 1951-1952, Ellenton (population 600) and Dunbarton (population 231) were the only towns on the plantsite. The communities of Leigh, Hawthorn, Robbins, and Meyers Mill were isolated aggregates of families. After acquisition of the site by the Government, honeysuckle invaded these areas, and fruit trees and ornamentals grew wild. At the time of Government acquisition, about 67% of the land area was forested, and 33% was in croplands and pastures. Cotton and corn were the chief crops. Abandoned fields passed through the annual broadleaf vegetation stage into the perennial grass stage and gradually became more wooded. Most of these abandoned fields have subsequently been planted in pine. From the viewpoint of wildlife management, habitat conditions are considered fair-to-excellent over the plantsite.

The Savannah River swamp on the south, particularly that portion subject to periodic flooding, and the dry sandy soils in the north are areas of limited terrestrial wildlife support. Although the swamp is supporting many wildlife species, the composition and age of vegetational species limit carrying capacity.

The region between the sandy sites on the north and the Savannah River swamp on the southeast is best suited for most of

the wildlife species because of the soil fertility and resultant favorable species composition. Much of the area is in pine plantations. Sawtimber is increasing as the pines grow. Ecological succession in the area of old townsites has reached the stage of maximum forage production (for deer). Hedgerows, ornamentals, and fruit trees also provide excellent wildlife habitats.

Artificial water impoundments are numerous. Five natural streams drain to the Savannah River from the site, the largest streams are Upper Three Runs and Lower Three Runs. In addition to the normal occurrence of warm water species of fish, these streams provide spawning runs for striped bass. The Savannah River swamp provides excellent habitat for fish in the numerous stream channels and oxbow lakes.

Vegetation

The plantsite is about evenly divided between Coastal Terraces and the Aiken Plateau (Figure II-52). The Aiken Plateau is quite hilly and deeply dissected by small streams. There are extensive areas of scrub oak and longleaf pine forest along the ridges. Many of the farms in this region were marginal in agricultural productivity. Soils in the Aiken Plateau are mostly sandy and low in fertility. Most of the soil is too sandy and excessively drained to yield regular, profitable crops.

Sandy loams occur in the Coastal Terraces subregion. Fertility is much greater in this area than on the sandy soils of the Aiken Plateau. Fluvial belts of sandy loams also occur along the streams that cross the SRP site. Farming in this area before construction of SRP was confined to the Sunderland and Brandywine terraces bordering the Savannah River floodplain.

Before Federal acquisition, there was very little timber management in the area. Generations of exploitive logging had resulted in poor stands of timber except for hardwoods in the floodplains; timber cutting in the floodplain was not overexploited because of limited access. Although much of the Savannah River Plant site now consists of managed pine forests, the composition of the naturally seeded forests of the site is closely related to the moisture available to the trees. Habitats range from very sandy, dry hilltops to continually flooded swamps. This continuous range is broken into zones characterized by communities of tree species.

The dry sandy areas[31] are typically covered with a scrub oak community dominated by longleaf pine, turkey oak, blue jack oak, black jack oak, and dwarf post oak with ground cover of three awn grass and huckleberry.

On more fertile, dry uplands, oak-hickory hardwoods are prevalent. The most characteristic species are white oak, post oak, southern red oak, mockernut hickory, pignut hickory, and loblolly pine, with an understory of sparkleberry, holly, greenbrier, poison oak, and poison ivy.

On more-moist soils, often found along small streams or on old floodplains, the composition is more variable. Trees may include tulip poplar, beech, sweetgum, willow oak, swamp chestnut oak, water oak, loblolly pine, and ash. The understory may include dogwood, *Viburnum*, holly, and red buckeye.

Bottomland hardwood forest[32] borders the Savannah River swamp where it is subject to occasional flooding. Here, small variations in elevation strongly affect the kinds of trees present. Some common trees are sweetgum, swamp chestnut oak, red maple, ash, laurel oak, blue beech, river birch, water oak, willow oak, sycamore, winged elm, and loblolly pine. Palmetto, switch cane, greenbrier, grape, crossvine, and trumpet creeper are common.

In the Savannah River swamp, where standing water is present most of the year, bald cypress and tupelo gum are dominant trees. Black gum, water elm, and water ash are also present.

Examples of habitat types at SRP have been reserved for research purposes. Two of these areas are registered with the Society of American Foresters as Natural Areas for the preservation of forest cover types. These are Boiling Springs Natural Area, an example of loblolly pine-hardwood (9 acres), and Scrub Oak Natural Area, an example of scrub oak-longleaf pine forest type (52 acres). Ten other areas[33] have been set aside as typical of the major ecosystems present on the plantsite:

1. Sandhills - 67 acres
2. Cypress Grove - 22 acres
3. Loblolly Stand - 28 acres
4. Steel Creek Bay - 29 acres
5. Mixed Swamp Forest - 91 acres
6. Beech Hardwood Forest - 118 acres
7. Oak-Hickory Forest - 83 acres
8. Old Fields - 350 acres
9. Risher Pond - 4 acres
10. Savannah River Ecology Laboratory Area - 100 acres of fields and pine woods

The ages of the major types of trees on the entire plantsite are summarized in Table II-25. Biologists[33-38] have recorded a variety (128 families, 871 species) of vascular plants on the plantsite.

TABLE II-25

Age of Major Types of Trees[39]

Age, years	*Acres*
Unclassified	640
1 - 10	21,720
10 - 20	77,080
20 - 30	24,560
30 - 40	15,400
40 - 50	19,560
50 - 60	13,760
60 - 80	17,360
80 +	8,440

Mammals

The populations of most species of mammals increased rapidly after the Savannah River Plant was officially closed to the public on December 14, 1952. Most notable expansion was in the deer herd, estimated to be about 20 animals in 1951. A virtual population explosion occurred; the present population is estimated to be greater than 20 deer per square mile or a total of about 5,000 to 8,000 deer on the plantsite. The greatest population densities occur on the southern and northeastern portions of the plantsite. Under protection, the populations expanded so rapidly that by the mid-1960s deer-vehicle collisions were common, and range deterioration was apparent. Controlled hunts, open to the public, were started in 1965. Approximately 10,000 deer have been killed in public hunts,[40] and about 500 have been killed for research purposes.

Domestic hogs, abandoned in 1952, reverted to the semiwild state and became detrimental to young forest plantations. A control program of hog removal was initially pursued by shooting and trapping. Currently, deer hunters are allowed to shoot the feral hogs, and about 125 have been killed since 1969.

Feral dogs and cats are present on the plantsite. Because the threat of rabies is always present and a few persons were chased by dogs, trapping is practiced and captured dogs without licenses are given to the S.P.C.A.

With the exception of deer, feral hogs, and feral dogs, there is no wildlife predation by man. Small mammals such as mice, rats, and shrews are common in favorable habitats. Animals that are common (C) or abundant (A) on the plantsite are:

Gray fox	(C)	Opossum	(C)
Raccoon	(C)	Cottontail rabbit	(A)
Wildcat	(C)	Gray squirrel	(A)
Red fox	(C)	Fox squirrel	(C)
Striped skunk	(C)	Beaver	(C)

Uncommon species found in favorable habitats include marsh rabbit and otter. Animals considered rare are spotted skunk, cane cutter rabbit, black bear, mink, and weasel.

Birds

Before acquisition of the plantsite by the Government, game birds, particularly quail and dove, were abundant due to extensive use of land for agriculture. The removal of land from agriculture did not decrease the quail population; the population increased and probably reached a record high in the early 1960s, but is declining because the conversion of agricultural fields to forest reduced the carrying capacity of the land for quail.[41]

Wild turkey, although present, were not very numerous. South Carolina Wildlife and Marine Resource initiated a program in 1972 using SRP as a breeding ground for wild turkey for stocking other parts of the state. Thirty-three birds were released on SRP by the end of 1974, and current estimates are that the turkey population has increased to about 200 birds.

Waterfowl are present but mainly during winter migrations. Winter waterfowl species increased in number and diversity after construction of Par Pond. An estimated 20,000 ducks and coots spend the winter on the site. Most of these are on Par Pond and several other large ponds and Carolina Bays. Perhaps 2,000 ducks spend the winter in the lower swamps and on the Savannah River. Wood ducks are the only waterfowl that commonly nest on the site.

Endangered species of birds that are protected on the SRP site are the bald eagle, the redcockaded woodpecker, and Kirtland's warbler. Biologists have identified 213 species of birds on the plantsite.[42]

Reptiles and Amphibians

The SRP site, with its wide diversity of aquatic and terrestrial habitats, supports a diverse population of reptiles and amphibians.[43-45] Species common to the southeastern Coastal Plain are found. Biologists[46,47] have identified 10 species of turtles, 10 species of lizards, 1 specie of alligator, 34 species of snakes, 15 species of salamanders, and 28 species of frogs and toads. Alligators, once rare, are now commonly seen in Par Pond and, to a lesser extent, in some of the effluent streams. This endangered species is protected on the SRP site.

Fish

Habitats for fish on the plantsite are numerous and diversified. They consist of natural and thermally stressed flowing streams, ambient temperature and thermally stressed reservoirs, Carolina Bays, abandoned farm ponds, swamp channels, and oxbow lakes. Fish are present throughout the thermally unaffected streams on the plantsite but are restricted to the lower reaches, near the Savannah River swamp and backwater pools, of streams carrying reactor cooling water.

Par Pond has been receiving heated reactor cooling water since 1958. Temperatures are elevated at one end and near ambient at the effluent end. The pond is connected to two reactor effluent streams (one reactor operating, one reactor shutdown since 1964) by a series of canals and smaller ponds (Figure II-41). Fish range throughout Par Pond and ponds on the canal network. However, due to the protected nature of the impoundment, populations are becoming unbalanced. Bass populations are excessively high, and other populations are declining. Major species occurring are largemouth bass, black crappie, bluegill, and redbreasted sunfish.

Most species not collected from the Par Pond system but reported in the effluent stream, Lower Three Runs, are those commonly considered to inhabit flowing waters. Two species have been collected from Par Pond but have not been recorded as present in Lower Three Runs. These are *Ictalurun platycephalus* (flat bullhead) and *Alosa aestivalis* (blueback herring). The latter commonly migrates up the Savannah River to spawn. An effort is being made to determine if this species is truly landlocked in the reservoir system. Recent evidence indicates that this species does become reproductive in this reservoir system. Species identified in streams number 36 in Upper Three Runs, 25 in Four Mile Creek, 16 in Pen Branch, 24 in Steel Creek, and 42 in Lower Three Runs. All streams except Lower Three Runs were sampled near the Savannah River swamp. Lower Three Runs was sampled 8 miles downstream from the Par Pond dam.

ENVIRONMENTAL PARK

The plant was designated as a National Environmental Research Park in June 1972. The various portions of the plantsite offer unusual opportunities for observing interactions between large industrial complexes and the environment. There are extensive areas of land protected from heavy traffic patterns, casual visitors, real estate development, and other disruptive influences. Because the land area is owned by the U.S. Government, long-term ecological research can be based at the Park with confidence in the continuation of the existing habitats. Several of the unusual opportunities offered are for observing and comparing the ecosystem changes brought about by heated water, flooding, atmospheric and aqueous emissions from fossil fuel power plants, uptake and retention of low levels of radioactive materials, forest management activities, and other stresses on the environment. Researchers from universities and government agencies are currently taking advantage of these opportunities for study.

BACKGROUND RADIATION

Background radiation is the base radiation level to which is added any dose from plant operations. Offsite environmental radiation measurements must take into account this radiation and its variation as a consequence of activities conducted beyond the site boundary. Natural background radiation includes both cosmic and terrestrial sources. These sources vary with location but are assumed constant with time within the recorded span of human history.[48] Local penetrating radiation from artificial origins, both fallout from nuclear detonations and prescribed medical exposures, varies with time for the population as a whole, and doses from the latter source vary from one individual to another. External exposure from radioactive fallout appears to be decreasing with time as a result of the nuclear test ban treaty,[49,50] while that from medical sources appears to be increasing as a result of increased use of diagnostic X-rays.[51]

The calculated annual background radiation dose received by the average person living in the vicinity of the Savannah River Plant is approximately 120 mrem from natural sources. An additional 100 mrem may be received on the average from medical X-rays. Its distribution is shown in Table II-26. The wide range of exposures (excluding those incurred for medical reasons) results primarily from the geologic distribution of naturally radioactive elements near the surface in this region.

In the vicinity of SRP, low-concentration placer deposits of uranium and thorium occur in the Atlantic Coastal Plain.

Slightly higher concentrations occur in the near-surface rocks of the Piedmont Plateau bordering the Coastal Plain on the northwest. These deposits cause substantial local variations in natural background radiation within the region. The radioactivity of these deposits on the plantsite and environs has been described in detail by Schmidt.[52]

TABLE II-26

Background Exposure Near SRP

	Estimated Whole Body Dose, mrem	
	Average[a]	*Range*[b]
Natural		
Cosmic Radiation	35	30-40
Terrestrial Deposits		
External	55	6-380
Ingested	27	25-30
Total Natural	117	61-450
Artificial		
Medical Diagnostic	101	*c*
Weapons Fallout		
External	1	
Ingested	4	3-8
Total Artificial	106	
Total Background	223	165-560

a. Central Savannah River Area (within 40 km of SRP perimeter)

b. Within 100 km of SRP perimeter

c. Only the average used in total range because of high individual variability

Cosmic Rays

Cosmic ray contribution to natural background dose varies with both latitude and altitude. SRP and the surrounding area out to 100 km lie between latitudes 33°N and 34°N with an altitude variation between sea level and roughly 300 meters (1000 ft).[53]

The ionizing component of cosmic radiation at sea level varies with latitude in the plantsite area by only about 0.5% of mean value,[54] less than the variation between measurements by different investigators (~3.7%).[55] The altitude effect on the ionizing component of cosmic radiation (based on doubling of the dose rate for every 1500-m increase in altitude[56]) causes an increase of from 1.4 to 5.8% over the sea level dose at the roughly 100- to 400-ft elevation of the general area surrounding the Savannah River Plant. The dose rate from this component of cosmic radiation is estimated at 29 mrad/yr based on a sea level rate of 28 mrad/yr.[57]

The dose equivalent rate from the neutron component of cosmic radiation is more difficult to estimate because of the wide variations in measurements[58] and the effect of self-shielding and secondary production in the body. Compared with the effects of these variations, the changes with latitude and altitude within the region of concern are negligible. Watt's experimental data[59] corrected for latitude and altitude give a value of 6 mrem/yr at SRP. Thus the total dose equivalent attributed to cosmic radiation in the vicinity of SRP is 35 mrem/yr.*

External Terrestrial Radiation

External terrestrial radiation in the vicinity of SRP is attributed primarily to gamma emitters in the natural radioactive series derived from uranium and thorium with some additional contributions from ^{40}K. Variation in the distribution of these minerals in local geologic formations and their inclusion in materials of construction commonly used in urban areas leads to a wide variation with location. Some typical values are shown in Table II-27. Because of the wide variation shown, the U.S. mean value of 55 mrem/yr[60] is chosen to represent the average external terrestrial background in the vicinity of SRP. Lowder and Condon[61] cite essentially the same rate, 1 mrem/week, for the average dose to persons living indoors.

* mrad is equivalent to mrem for the ionizing component of cosmic radiation and for external terrestrial radiation.

TABLE II-27

External Gamma Fields from Natural Terrestrial Radioactivity[a], mrem/yr

	Aircraft Surveys	*SRP Mean (70)*	*Other*
Augusta, Ga.	17- 85 (58)		56 (71)
Waynesboro, Ga.	17- 46 (58)	26	
Aiken, S. C. (Airport)	17- 34 (58)	19	26 (63) 24 (65)
Barnwell, S. C.[b]	6- 51 (58)	35	
Edgefield, S. C.[b]	11-154 (58)		23- 95 (63)
Lexington, S. C.[b]	17-385 (58,63)		20-140 (63)
Columbia, S. C.	35-385 (63)		80 (58) 70 (71)

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a. Number in parentheses is year of measurement. Source of data is also given.

(58) Reference 52

The aeroradioactivity survey readings reported by Schmidt in counts per second (cps) at 500 ft altitude were corrected for background due to fallout (150 cps) and converted to mrem/yr at 3 ft by the factor 1 mrem/hr at 3 ft = 77,000 cps at 500 ft (Reference 52, p 13). This is considered a better conversion factor than the 1 μrem/hr = 37 cps derived from the correlation curve supplied by Schmidt (Reference 52, p 17) because the latter was based on ground readings in the μrem/hr range which are subject to considerable uncertainty.

Reference 59

(63) References 62 and 63

(65) Reference 64

(70) Reference 65

(71) Lawrence Livermore Laboratory measurements

b. 10-mile radius

Internal Radiation

Internal radiation from natural sources arises primarily from ^{40}K, ^{14}C, ^{87}Rb, and daughters of ^{226}Ra. Contributions from these sources are shown in Table II-28. No estimate of variation with location is attempted because widespread distribution of fertilizers and foods as well as population mobility has an averaging effect for these natural long-lived radionuclides that produce the internal dose.

TABLE II-28

Estimated Average Annual Whole-Body Internal Radiation Dose from Natural Radioactivity

Nuclide	*Dose, mrem*	*Year*	*Source of Data*
^{3}H	<0.01	1962	Reference 66, p 217, paragraph 84
^{14}C	1.0	1962	Reference 66, p 216-216, paragraph 82
^{40}K	19	1962	Reference 66, p 216, paragraph 80
^{87}Rb	0.6	1966	Reference 66, p 27, paragraph 136 (QF[a] = 2)
^{210}Po	3.0	1966	Reference 67, p 35, Table XVI (QF = 10)
^{222}Rn	3.0	1962	Reference 66, p 212, paragraph 41 (QF = 10)
Total	27.0		

a. Quality factor.

ENVIRONMENTAL STUDIES BY OUTSIDE CONTRACTORS, UNIVERSITIES, AND RESEARCHERS

Academy of Natural Sciences of Philadelphia Studies of the Savannah River

Before the start of plant construction in 1951, the Limnology Department of the Academy of Natural Sciences of Philadelphia began a baseline study of the Savannah River in the vicinity of the Savannah River Plant. This study considered all the major groups of aquatic organisms (protozoa, lower invertebrates, insects, fish, and algae) together with the general chemical and physical characteristics of the river.[68] The purpose of this study was to provide a comprehensive picture so that future changes that might occur in the Savannah River could be measured. Such changes might be due to the activities of the Savannah River Plant or to changes in upstream river conditions.

Since the baseline study, the Limnology Department has carried on a continuous program of scientific investigation in the Savannah River, as follows:

1. Detailed surveys of the biological, chemical, physical, and bacteriological aspects have been made at 3- to 5-year intervals.

2. Checks on river conditions are made four times yearly; the general condition of algae, invertebrate, and fish populations are determined.

3. Diatometer studies were begun in 1953 to continuously record changes that may occur in river conditions as indicated by changes in the structure of the diatom community.

At the time the baseline study was made, the Savannah River was a typical Coastal Plain river receiving a moderate amount of city and industrial waste along its course. There was a heavy silt load. In 1952 shortly after the first study was made, Clark Hill Dam was put into operation upriver from the plant. This dam has had several effects on the river. Because of stabilized river flow, cave-ins of the banks due to rapidly rising and falling water no longer occur. The banks are vegetated with higher plants that hold the soil in place. Also, suspended solids tend to settle out behind Clark Hill Dam, with the result that downstream waters are clearer. Algal growth extends to a much greater depth, and populations of filter-feeding insects have increased, resulting in an increase in aquatic life in the Savannah River below the dam.

When the baseline study was made, and continuing to the present time, the cities of Augusta and North Augusta contributed raw or partially treated sewage to the river. This was the major source of pollution within a short distance upstream. Since that time, a number of industries have located between Augusta and the Savannah River Plant, and many discharge effluents either directly or indirectly into the river. Some industries that were small at the time of the baseline survey have enlarged. The city of Augusta now treats all sewage before discharge.

Biological and chemical evidence indicates that the mineralized nutrient load increased in this section of the river during the study period. These conditions have produced a decrease in diversity and a change in the more common species. The changes have not been severe enough, however, to degrade the river below a healthy condition. There was no evidence in the areas studied of any effects of the slight increases in temperature of the river caused by the Savannah River Plant.

Savannah River Ecology Laboratory Studies of the SRP Site

The Savannah River Ecology Laboratory (SREL) of the University of Georgia was established in 1961 to study the ecology of the SRP site. It has conducted diversified studies of site characteristics to identify and follow natural changes since acquisition of the property in 1950 as well as to investigate the effects of SRP operations. Research is currently centered in three major programs: thermal ecology, mineral cycling, and radioecology of transuranic elements. Each of these programs is strengthened by the ongoing accumulation of knowledge of the basic ecology of the site.

Emphasis in all programs is placed on field-oriented research dealing with unique regional problems or those of local origin which have broad ecological significance. As examples of the latter, extensive research has been conducted in the Par Pond reservoir system and the Savannah River swamp, both of which have received thermal effluents and low levels of radioisotopes. Furthermore, the availability of low levels of plutonium and uranium in both terrestrial and aquatic environments on the Savannah River Plant has provided an unusual opportunity for field research in this area. SREL studies seek to document the effects and determine the extent of local environmental effects and establish predictable relationships which have regional applicability. A limited number of the SREL regional studies require data collected from several southeastern states. Studies in the natural, environmentally unaffected areas on the SRP are also a vital part of the overall program. The combination of thermally and isotopically altered natural environments in the immediate vicinity of unaffected areas has resulted in a unique field research facility.

SRP Site Ecology

The forests and pine plantations of SRP are actively managed for pulp and timber production by the U.S. Forest Service, using management techniques which are standard throughout the southeast. The evaluation of forest management techniques in this region is a continuous process for numerous federal and state agencies. SREL is studying the nutrient cycle which exists in the soils of the southeastern Coastal Plain in order to effectively devise management techniques which are compatible with productivity and conservation.

In addition to the wood resources of the SRP, there are animal resources, such as an estimated 5,000-8,000 white-tail deer and 500-1,000 feral swine. These as well as other game and non-game species are managed by the Forest Service and studied by SREL. Special management of other species is required by the Endangered Species Act of 1973 (PL-93-205), that requires all Federal agencies be cognizant of those endangered species of wildlife and plants which occur on lands under their management, carry out programs for the conservation of endangered species, and take action necessary to ensure that actions authorized, funded, or carried out by them do not jeopardize the continued existence of endangered species or result in the destruction or modification of critical habitat of such species. At least two endangered species, the American alligator (*Alligator mississippiensis*) and the redcockaded woodpecker (*Dendrocopos borealis*) are found on the Savannah River Plant, and both of these are being studied by SREL personnel.

Thermal Ecology

The following objectives have guided SREL research in thermal studies:

- To determine how elevated water temperatures resulting from reactor effluents affect selected physical parameters of the environment having direct effects on biological systems.

- To determine how elevated water temperatures influence the uptake and availability of nutrients, heavy metals, and other elements to organisms associated with aquatic ecosystems.

- To determine the effect of the artificial elevation of aquatic temperatures on primary and secondary productivity (including reproduction and growth processes) in aquatic communities.

- To determine how individuals and species populations respond to artificial elevation of aquatic temperatures through differential thermal tolerances, behavior patterns, host-parasite relationships, genetic selection, and alteration of competitive interactions.

- To determine how communities respond to the artificial elevation of aquatic temperatures through changes in species composition and diversity.

SREL studies have revealed the following apparent effects of reactor thermal effluents on the environment of the SRP:

1) An assessment of the broad-scale effects of reactor effluents on the forest vegetation of the Savannah River swamp has revealed that:[69]

   a) The trees on 560 acres of the swamp forest have been killed by heated reactor cooling water. This represents 7.5% of the total swamp area into which effluents are released.

   b) One-third to two-thirds of the trees have been killed in another 650-acre area (8.7% of the total swamp), and the forest canopy is open.

   c) In an additional 3,450 acres (46.2% of the total swamp), mortality of swamp hardwoods includes fewer than one-third of the trees but more than that found in the natural swamp upstream of all heated effluents. The canopy is uneven.

2) Studies on aquatic vertebrates have revealed a number of effects on these groups of organisms. Among these are the following:

   a) Bass are attracted to the thermal areas in large numbers during winter.[70]

   b) Thermal tolerances of bluegill are increased in thermal areas.[71]

   c) Amphibian growth rates are increased but body sizes at metamorphosis are reduced in thermal areas.[72]

   d) Growth rate and body size of some turtle species are increased in thermal and post-thermal recovery areas.[73]

e) Some alligators, principally larger males, in the thermal areas, remain active throughout the normal period of winter dormancy.[74]

f) Diversity of fish and reptiles is decreased in areas of greatest thermal impact.[75]

g) Certain species of waterfowl avoid thermal areas while others do not.[76]

h) Several species of fish and turtles inhabiting thermal areas demonstrate significant changes in kinds and population densities of parasites.

3) Plant ecology studies have revealed several findings other than the general impact on the swamp.[77]

a) Tree species diversity is reduced in thermal and early post-thermal recovery areas.

b) Accompanying the shift from hardwood floodplain to freshwater marsh, the diversity of herbaceous shoreline and island plants remains high in thermal and post-thermal areas.

c) Diversity of submerged plants is greatly reduced in hot water. Periphyton communities have shifted from green algae to blue-green algae.

d) Species composition of plant communities is greatly changed in both thermal and post-thermal areas.

e) Cattails from the thermal areas have a lower biomass per unit area than those from normal temperature areas. Also, sexual reproduction is absent in heated areas.

Mineral Cycling

Research objectives for the mineral cycling program at SREL are:

- To determine the availability of stable elements and radio-isotopes to the biota of the southeastern Coastal Plain.
- To determine the role of primary producers and consumers in cycling processes in southeastern ecosystems.
- To determine the factors that are limiting to rate processes in southeastern ecosystems.

- To determine the importance of interactions among energy flow, thermal environments, and mineral cycling processes on the rates of biomass buildup and transfer within southeastern ecosystems.

- To determine the extent to which transfer coefficients are modified by population processes that influence the temporal or spatial turnover of standing crops.

- To validate models of cycling processes in southeastern ecosystems at various sites on the southeastern Coastal Plain.

The Savannah River Plant provides opportunities to investigate various interactions of heavy metal and other stable element cycling between the biological and physical components of the environment. The broad list of available habitats includes reservoirs, ponds, swamps, streams, a major river system, abandoned agricultural land, forest plantations, and several natural forest types. Some of these habitats have received various radioisotopes and industrial pollutants from plant operations for many years. Because of the porous sandy soils of this area, many minerals normally held in the organic or clay fraction of soils become concentrated in the biota. This creates rather tightly closed mineral loops in the biota and reduces nutrient loss, but can also result in the accumulation of toxic pollutants.

The Savannah River Ecology Laboratory has conducted studies in contaminated habitats on the fate of radionuclides in the environment. The low activity levels of these radioisotopes in well-defined ecosystems provide a unique opportunity to study the fates of these isotopes under natural conditions.

Studies have been concentrated in the swamp ecosystem, especially in the Steel Creek area. Studies have also been done with radioisotopes in the Par Pond system. Because radiocesium is among the few long-lived isotopes that have been released and is biologically active, most of SREL's research efforts in this area have been focused on radiocesium.[78,79]

Radioecology of Transuranic Elements

Evaluation of potential hazards to the quality of the environment and health of man from low-level releases of the transuranium nuclides (e.g., ^{238}Pu, $^{239-240}Pu$, ^{241}Am, and ^{244}Cm) was initiated as a new program in 1974. This program is considered independent of general mineral cycling studies because of the unique properties of transuranic elements, their potential long-term persistence in the environment, and the potentially serious environmental problems they pose.

Evaluations include research in recipient areas at SRP, such as old fields, agricultural fields, forest ecosystems, and streams. The emphasis is on the soil (and atmospheric)-plant-animal-man pathway of these radionuclides. In agricultural ecosystems, the focus is on major commercial crops used for livestock and human foodstuff. In aquatic ecosystems, the emphasis is on fish and other commercially important aquatic foods - both important for animal and man needs. In natural terrestrial (old field and forest) ecosystems, the focus is on vegetation which is part of the diet of mammals, such as deer.